

Nuclear Physics Electronics Design and Fabrication

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The official link for this solicitation is: <http://science.energy.gov/sbir/funding-opportunities/>

Agency:
Department of Energy

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Application Due Date:
October 19, 2015

Solicitation:
[DOE SBIR/STTR 2016](#)

Close Date:
October 19, 2015
Topic Number:
22

Description:

Please Note that a Letter of Intent is due **Tuesday, September 08, 2015 5:00pm ET**

Program Area Overview

Office of Nuclear Physics

Nuclear physics (NP) research seeks to understand the structure and interactions of atomic nuclei and the fundamental forces and particles of nature as manifested in nuclear matter. Nuclear processes are responsible for the nature and abundance of all matter, which in turn determines the essential physical characteristics of the universe. The primary mission of the Nuclear Physics (NP) program is to develop and support the scientists, techniques, and facilities that are needed for basic nuclear physics research and isotope development and production. Attendant upon this core mission are responsibilities to enlarge and diversify the Nation's pool of technically trained talent and to facilitate transfer of technology and knowledge to support the Nation's economic base.

Nuclear physics research is carried out at national laboratories and accelerator facilities, and at universities.

The Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator

Facility (TJNAF) allows detailed studies of how quarks and gluons bind together to make protons and neutrons.

In an upgrade currently underway, the CEBAF electron beam energy will be doubled from 6 to 12 GeV. The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) is forming new states of matter, which have not existed since the first moments after the birth of the Universe; a beam luminosity upgrade is currently underway. NP is supporting the development of a future Facility for Rare Isotope Beams (FRIB) currently under construction at Michigan State University. The NP community is also exploring opportunities with a proposed electron-ion collider.

The NP program also supports research and facility operations directed toward understanding the properties of nuclei at their limits of stability, and of the fundamental properties of nucleons and neutrinos. This research is made possible with the Argonne Tandem Linac Accelerator System (ATLAS) at Argonne National Laboratory (ANL) which provides stable and radioactive beams as well as a variety of species and energies; a local program of basic and applied research at the 88-Inch Cyclotron of the Lawrence Berkeley National Laboratory (LBNL); the operations of accelerators for in-house research programs at two universities (Texas A&M University and the Triangle Universities Nuclear Laboratory (TUNL) at Duke University), which provide unique instrumentation with a special emphasis on the training of students; non-accelerator experiments, such as large standalone detectors and observatories for rare events. Of interest is R&D related to future experiments in fundamental symmetries such as neutrinoless double-beta decay experiments and measurement of the electric dipole moment of the neutron, where extremely low background and low count rate particle detections are essential. Another area of R&D is rare isotope beam capabilities, which could lead to a set of accelerator technologies and instrumentation developments targeted to explore the limits of nuclear existence. By producing and studying highly unstable nuclei that are now formed only in stars, scientists could better understand stellar evolution and the origin of the elements.

Our ability to continue making a scientific impact on the general community relies heavily on the availability of cutting edge technology and advances in detector instrumentation, electronics, software, accelerator design, and isotope production. The technical topics that follow describe research and development opportunities in the equipment, techniques, and facilities needed to conduct and advance nuclear physics research at existing and future facilities.

For additional information regarding the Office of Nuclear Physics priorities, [click here](#).

TOPIC 22: Nuclear Physics Electronics Design and Fabrication

Maximum Phase I Award Amount: \$150,000	Maximum Phase II Award Amount: \$150,000
Accepting SBIR Phase I Applications: YES	Accepting SBIR Fast-Track Applications: YES
Accepting STTR Phase I Applications: YES	Accepting STTR Fast-Track Applications: YES

The DOE Office of Nuclear Physics seeks new developments in detector instrumentation electronics with significantly improved energy, position, timing resolution, sensitivity, rate capability, stability, dynamic range, durability, pulse-shape discrimination capability, and background suppression. Of particular interest are innovative readout electronics for use with the nuclear physics detectors described in Topic 24 (Nuclear Instrumentation, Detection Systems, and Techniques).

All grant applications must explicitly show relevance to the DOE nuclear physics program. Additionally, applications must be informed by prior art in nuclear physics applications, commercially available products and emerging technologies. A proposal based on incremental improvements or little innovations, in the right context, can have an enormous impact or value. Such a proposal must be convincing, otherwise it will be considered as being non-responsive.

Grant applications are sought only in the following **subtopics**:

a. Advances in Digital and High-Density Analog Electronics

Digital signal processing electronics are needed to replace analog signal processing, following low noise amplification, in nuclear physics applications. Grant applications are sought to develop high speed digital processing electronics that improve the accuracy in determining the position of interaction points (of particles or photons) to smaller than the size of the detector segments. Emphasis should be on digital technologies with low power dissipation.

Questions – Contact: Manouchehr.farkhondeh@science.doe.gov. Also can contact the NP Topic Associate (TA) listed at the beginning of the References section for this topic.

b. Circuits

Grant applications are sought to develop application-specific integrated circuits (ASICs), as well as circuits (including firmware) and systems, for rapidly processing data from highly-segmented, position-sensitive germanium detectors (pixel sizes in the range of 1 mm² to 1 cm²) and from particle detectors (e.g., gas

detectors, scintillation counters, silicon drift chambers, silicon pixel and strip detectors, silicon photomultipliers (SiPMs), particle calorimeters, and Cherenkov counters) used in nuclear physics experiments. Areas of specific interest include (1) low-noise preamplifiers, low-noise filters, peak sensors, timing sensors, analog storage devices, analog-to-digital and time-to-digital converters, transient digitizers, and time-to-amplitude converters; (2) front-end, digitizing, and multiplexing circuits operating in cryogenic environment, to allow for reduction of noise, power, and number of feed throughs in highly segmented germanium detectors and noble liquid Time Projection Chambers (TPCs); (3) readout electronics for solid state pixelated detectors, including interconnection technologies, charge sharing processing and correction circuits (pixel pitch below 250 μ m); (4) circuits for high dynamic range, and (5) systems on chip that embody low-noise front-end circuits, analog-to-digital converters, extensive digital signal processing capability tailored to the application, and standard digital interfaces and protocols for compatibility with commercial devices. These circuits should be low-power; low-cost; high-density; programmable to the possible extent; easy to use with commercial auxiliary electronics; compact; and efficiently packaged for multi-channel devices. Also of interest are the following high performance detector readouts:

- Multi-channel Time to Digital Conversion front end ASIC (conventional and radiation hard) for picosecond measurement resolution, over a wide timing range (~1-10 s).
- Flash ADC using CMOS or superconducting electronics with sampling frequency greater than 50 GHz and sampling depth of 1024-4096 (10-12 bits).

Grant applications are sought for microelectronics beyond the current state-of-art that specifically target low-noise amplification, digitization and smart on-chip processing (triggering, neighboring, sparsification, data reduction) of sensor/detector signals, and that are suitable for next generation detectors. The microelectronics and associated interconnections must be lightweight and have low power dissipation.

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c. Advanced Devices and Systems

Grant applications are sought for improved or advanced devices and systems used in conjunction with the electronic circuits and systems described in subtopics a and b:

- Areas of interest regarding devices include (1) wide-bandgap semiconductors (i.e., semiconductor materials with bandgaps greater than 2.0 electron volts, including Silicon Carbide (SiC), Gallium Nitride (GaN), and any III-Nitride alloys); (2) inhomogeneous semiconductors such as SiGe; and (3) device processes such as silicon-on-insulator (SOI) or silicon-on-sapphire (SOS).
- Areas of interest regarding systems include (1) bus systems, data links, event handlers, multiple processors, trigger logics, and fast buffered time and analog digitizers. For detectors that generate extremely high data volumes (e.g., >500 GB/s), (2) advanced high-bandwidth data links are of interest.

Grant applications also are sought for generalized software and hardware packages, with improved graphic and visualization capabilities, for the acquisition and analysis of nuclear physics research data.

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d. Next Generation Pixel Sensors

Active Pixel Sensors (APS) in CMOS (complementary metal-oxide semiconductor) technology have largely replaced Charge Coupled Devices as imaging devices and cameras for visible light. Nuclear physics experiments at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory and at the Large Hadron Collider (LHC) at CERN have developed and used APS devices as direct conversion minimum ionizing particle detectors. The innermost tracking detector of the STAR experiment at RHIC contains 356 million (21x21x50 m) APS pixels.

Future high luminosity colliders such as the Electron Ion Collider (EIC) plan to operate at luminosities in the range 10^{33} – 10^{35} cm⁻² s⁻¹ and will require radiation hard tracking devices placed at radii below 10 cm. Therefore, cost effective alternatives to the present generation high density APS devices will be required. An ambitious goal is to develop extremely thin ~0.1% radiation length detector modules capable of high rate readout. In low energy nuclear physics applications, the bulk silicon substrate is thicker and is used as the active volume. A major advance would be to introduce an electric field into this drift region and to deplete it. This would result in a much shorter collection time and negligible charge dispersion allowing sensitivity to non-minimum ionizing particles, such as MeV-range gamma rays. Grant applications also are sought for the next generation of active pixel sensors, or even strip sensors. Options may include integrated CMOS detectors which combine initial signal processing and data sparsification on a standard CMOS wafer; superconducting large area pixel detectors; novel 2D and 3D pixel materials and geometry structure.

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e. Manufacturing and Advanced Interconnection Techniques

Grant applications are sought to develop (1) manufacturing techniques for large, thin, multiple-layer printed circuit boards (PCBs) with plated-through holes, dimensions from 2m x 2m to 5m x 5m, and thicknesses from 100 to 200 microns (these PCBs would have use in cathode pad chambers, cathode strip chambers, time projection chamber cathode boards, etc.); (2) techniques to add plated-through holes, in a reliable robust way, to large rolls of metallized mylar or kapton (which would have applications in detectors such as time expansion chambers or large cathode strip chambers); and (3) miniaturization techniques for connectors and cables with 5 times to 10 times the density of standard inter-density connectors.

In addition, many next-generation detectors will have highly segmented electrode geometries with 5-5000 channels per square centimeter, covering areas up to several square meters. Conventional packaging and assembly technology cannot be used at these high densities. Grant applications are sought to develop (1) advanced microchip module interconnect technologies that address the issues of high-density area-array connections – including modularity, reliability, repair/rework, and electrical parasitics; (2) technology for aggregating and transporting the signals (analog and digital) generated by the front-end electronics, and for distributing and conditioning power and common signals (clock, reset, etc.); (3) low-cost methods for efficient cooling of on-detector electronics; (4) low-cost and low-mass methods for grounding and shielding; and (5) standards for interconnecting ASICs (which may have been developed by diverse groups in different organizations) into a single system for a given experiment – these standards should address the combination of different technologies, which utilize different voltage levels and signal types, with the goal of reusing the developed circuits in future experiments.

Lastly, highly-segmented detectors with pixels smaller than 100 microns present a significant challenge for integration with frontend electronics. New monolithic techniques based on vertical integration and through-silicon vias have potential advantages over the current bump-bonded approach. Grant applications are sought to demonstrate reliable, readily-manufacturable technologies to interconnect silicon pixel detectors with CMOS front-end integrated circuits. Of highest long term interest are high density high-functionality 3D circuits with direct bonding of high resistivity silicon detector layer of an appropriate thickness (50 to 500 microns) to a 3D stack of thin CMOS layers. The high resistivity detector layer would be fully depleted to enable fast charge collection with very low diffusion. The thickness of this layer would be optimized for the photon energy of interest or to obtain sufficient signal from a minimum number of ionizing particles.

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f. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the general description at the beginning of this topic.

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